

## MCNP Comparison With Point Source Measurements From a Portable HPGe System

Robert Hayes

Remote Sensing Laboratory: MS RSL-47, P.O. Box 98521, Las Vegas, NV 89193, hayesrb@nv.doe.gov

### INTRODUCTION

The Ortec trans-SPEC is a portable gamma ray spectrometer which is approximately 10.4 kg in total weight and 37 cm × 16 cm × 32 cm in overall size. It utilizes a P-type 50 mm diameter and 30 mm height coaxial HPGe detector and has more than 3 hours of battery life when fully charged.

This paper details the experimental agreement found for one of these detector units and that of MCNP5 [1] calculations. The purpose of carrying out this work is to evaluate the potential utility of the spectrometer for emergency response (consequence management) applications.

### EXPERIMENTAL

Using button sources (3 mm thick and 2.5 cm diameter), spectra were taken at various coaxial distances. Sources utilized were Co-60, Cs-137 and Ba-133 each having an activity of approximately 40 uCi. Spectra were taken for 1 minute intervals based on calculated live time. Photopeak values were obtained using the commercial software package Maestro®-32. This approach utilized a superposition of a Gaussian (for the peak) and a line (for the background) where the resultant integration of the isolated Gaussian represents the photopeak measurement.

Initial attempts to determine the crystal location behind the outer coverings were done by fitting both inverse square and solid angle functions to the data using the Levenberg-Marquardt algorithm [2] in the software program Kaledagraph®. The solid angle formula used is given in Equation (1) and is based on a point source and disk detector where the detector response is  $R$ , the fitted parameters are a magnitude  $m1$ , a disk radius  $m2$  and a distance of the detector below the exterior covering  $m3$  (all measurement distances were based on the distance to the covering). This was done to estimate the actual position of the crystal behind the exterior covering layers.

$$R = m1 \cdot \left( 1 - \frac{1}{\sqrt{1 + \left( \frac{m2}{L + m3} \right)^2}} \right) \quad (1)$$

An example of the fitted results is shown in Figure 1. Here the data was taken from the Co-60 values from the 1.33 MeV peak. What can be seen from this figure is the lack of exact correlation with the detector radius ( $m2$ ) and that of the crystal (2.5 cm). Also note that the distance behind the exterior cap (approximately 3 cm) of the

crystal does not exactly match the fitted value  $m3$  within the modeled error (note that the curve fit parameters are also shown in the inset).

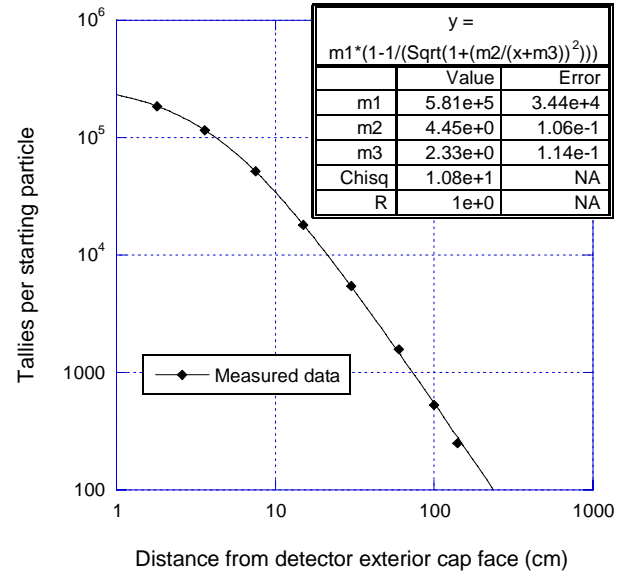


Fig 1. Result of fitting a disk response (Eqn. 1) to that of a coaxial P-type HPGe detector for estimation of axial offset and detector diameter values.

Still, when using Equation (1) on all the isotopes, the offset tended to be about 3 cm which after subsequent perturbation analysis showed overall, this appeared to be an acceptable offset value.

### MCNP MODELING AND CALCULATIONS

The MCNP model of the detector and source is shown in Figure 2. Here the various materials are labeled to the extent practical. Note that only the air between the source and detector housing was modeled as only photopeaks are extracted from the measured spectrum as no scatter components are of interest for this application. All MCNP results were obtained using the f8 tally with all internal statistical checks meeting or exceeding minimum requirements for passing.

The source is modeled as a Lucite disk with a point source although the actual source was located within a 1 mm diameter sphere inside the disk.

Tally results were obtained by defining each photons energy range for its tally bin to be 0.1 eV above and below its actual value so that scatter components in the bin could be considered negligible. In this way, all 3 isotopes were simulated together at all distances even

though the actual measurements were done with the sources at the same distances but at different times. This required multiplying the resultant tallies from each isotope by an additional factor of 3 due to the internal MCNP normalization of all tallies to be per starting particle. Each individual photon was weighted by its branching ratio in percent.

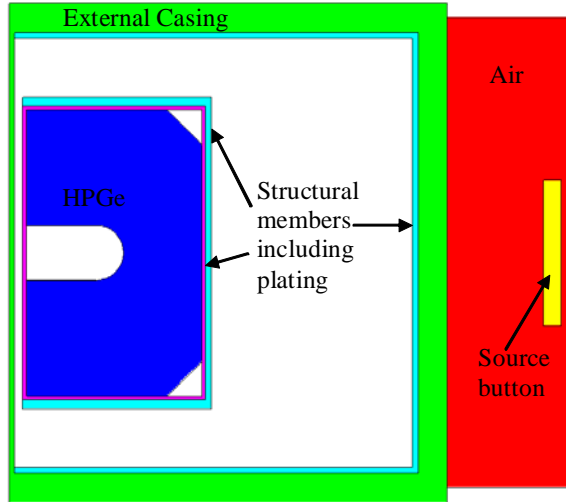


Fig. 2. Labeled MCNP model of source and detector. The actual activity was modeled as a point in the source button but was actually about 1 mm diameter.

## RESULTS

The ratio's of calculated to evaluated (C/E) values are shown in Table 1. Although a number of values have total propagated errors (based on both the peak fitted errors and the MCNP statistical errors) resulting in z-scores with magnitudes greater than 4 (highlighted in bold face) the overall results are still within 15 to 20% excluding the 81 keV results.

The one measurement on the side of the detector for the Ba-133 resulted in 81 keV;  $0.97 \pm 0.01$ , 161 keV  $1.20 \pm 0.30$ , 223 keV;  $0.88 \pm 0.16$ , 276 keV;  $1.02 \pm 0.02$ , 302 keV;  $1.04 \pm 0.01$ , 356 keV;  $1.01 \pm 0.01$  and 384 keV;  $1.01 \pm 0.02$ . The side mounting straps [3] were modeled here as a single layer of 4 mm thick to attain the agreement at 81 keV which was not done for the values in Table 1 indicating more attenuation could be present on the end than being modeled. This not necessarily inconsistent with the curve fit predictions as shown in Figure 1 given the lack of consistency found using that approach.

## DISCUSSION

The results in Table 1 show that there is statistical bias in the results which can be attributed to physical configuration elements not modeled by MCNP. These could be collection efficiencies based on the electric field

distributions or actual crystal configurations or even peripheral shielding elements in the instrument housing. In fact, Ortec itself recommends conducting an individual crystal calibration of position and energy efficiencies in order to account for crystal specific variations [3, 4]. Reported values from Ortec range within 20% which agree in magnitude with the potential biases seen in table 1 when the 81 keV results are excluded.

TABLE I. C/E values for coaxial configurations using an assumed 3 cm distance from the outer casing face to the crystal surface. Values in bold show results deviating more than 4 standard deviations from unity.

Energy (keV)	C/E at 1.8 cm	C/E at 3.6 cm	C/E at 7.5 cm	C/E at 15 cm	C/E at 30 cm
81	<b>3.17</b> $\pm 0.02$	<b>2.79</b> $\pm 0.01$	<b>2.87</b> $\pm 0.02$	<b>3.09</b> $\pm 0.08$	<b>3.18</b> $\pm 0.05$
161	1.04 $\pm 0.06$	0.91 $\pm 0.06$	0.92 $\pm 0.07$	0.93 $\pm 0.17$	1.12 $\pm 0.33$
223	0.87 $\pm 0.07$	0.87 $\pm 0.07$	0.92 $\pm 0.09$	1.17 $\pm 0.27$	NA
276	1.06 $\pm 0.02$	0.97 $\pm 0.01$	1.03 $\pm 0.01$	1.07 $\pm 0.09$	<b>1.18</b> $\pm 0.04$
302	<b>1.09</b> $\pm 0.01$	0.96 $\pm 0.01$	1.02 $\pm 0.01$	1.07 $\pm 0.07$	<b>1.16</b> $\pm 0.02$
356	0.99 $\pm 0.01$	<b>0.92</b> $\pm 0.004$	0.96 $\pm 0.005$	1.03 $\pm 0.05$	<b>1.10</b> $\pm 0.01$
384	0.94 $\pm 0.02$	<b>0.93</b> $\pm 0.01$	0.97 $\pm 0.01$	1.04 $\pm 0.09$	1.12 $\pm 0.03$
662	<b>1.21</b> $\pm 0.01$	<b>0.88</b> $\pm 0.005$	1.00 $\pm 0.01$	1.07 $\pm 0.06$	<b>1.14</b> $\pm 0.01$
1173	1.01 $\pm 0.01$	1.00 $\pm 0.01$	1.01 $\pm 0.01$	1.10 $\pm 0.07$	<b>1.16</b> $\pm 0.02$
1333	0.99 $\pm 0.01$	<b>0.97</b> $\pm 0.01$	0.99 $\pm 0.01$	1.08 $\pm 0.07$	<b>1.14</b> $\pm 0.02$

The discrepancy at 81 keV could very well be a lack of full optimization between unknown shielding layers in the housing and the unknown crystal depth beneath the external housing surface. That extra side shielding was sufficient to bring the 81 keV results into agreement with the higher energies suggests it is not unreasonable to expect that a similar change in the end shielding could give similar agreeable results if the offset is appropriately adjusted although this cannot be concluded at present. It is suggestive that the results in Table 1 are a compromise between an unknown shielding amount and the modeled distance offset for the unknown depth of the crystal behind the external protective face. This is based on the assumption that no offset needed to be modeled for the side measurements due to the axial symmetry and the known diameter of the crystal (fixing its position in a known configuration).

## CONCLUSIONS

Coaxial measurement verification has been demonstrated to within 15 or 20% above 150 keV. Off axis measurements required some additional shielding to agree with the measured values which are attributed to features not modeled (such as mounting straps). On axis measurements required an unknown axial position offset representing the crystals position below the face which was unknown. Curve fitting response values as a function of source position to determine this offset was not definitive but helpful nonetheless. Although clear systematic bias still exists based on statistical results, useful assay results can be expected to be obtained as found with 38mm  $\times$  38mm  $\times$  51 mm NaI measurements [5]. Overall, with additional shielding and/or crystal positional offsets, simulated results were found to agree with measured values to within approximately 20% overall.

## REFERENCES

1. X-5 MONTE CARLO TEAM, "MCNP — A General Monte Carlo N-Particle Transport Code, Version 5, Volume I: Overview and Theory," LA-UR-03-1987, Los Alamos National Lab. (April 2003)..
2. W. H. PRESS, S. A. TEUKOLSKY, W. T. VETTERLING, B. P. FLANNERY. *Numerical Recipes in C, The Art of Scientific Computing*, 2<sup>nd</sup> Edn. Cambridge University Press, Cambridge, pp. 683-688 (1997).
3. R. M. KEYSER. Resolution and Sensitivity as a Function of Energy and Incident Geometry for Germanium Detectors. *Proceedings of the IRRMA Meeting*. Bologna, Italy, June (2002) See also <http://www.ortec-online.com/papers/irrma2002paper.pdf>.
4. R. M. KEYSER, W. K. HENSLEY. Efficiency and Resolution of Germanium Detectors as a Function of Energy and Incident Geometry. Presented at IEEE, Nov. (2002). See also <http://www.ortec-online.com/papers/ieee1102.pdf>
5. J. HUTHINSON, N. HERTEL. Handheld gamma-ray spectrometry for assaying radioactive materials in lungs. *The American Nuclear Society's 14<sup>th</sup> Biennial Topical Meeting of the Radiation Protection and Shielding Division*. Carlsbad, New Mexico. April 3-6 (2006).

This manuscript has been authored by Bechtel Nevada under Contract No. DE-AC08-96NV11718 with the U.S. Department of Energy. The United States Government retains and the publisher, by accepting the article for publication, acknowledges that the United States Government retains a non-exclusive, paid-up, irrevocable, world-wide license to publish or reproduce the published form of this manuscript, or allow others to do so, for United States Government purposes.